AFFTC-PA-11316

Can Wing Tip Vortices Be Accurately Simulated?

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JULY 2011

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
26 07 2011	Poster	June 2011-July 2011

4. TITLE AND SUBTITLE
Can Wing Tip Vortices Be Accurately Simulated?

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
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5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
812 TSS/ENTT
307 E. Popson Ave.
Edwards AFB, CA 93524

8. PERFORMING ORGANIZATION REPORT NUMBER
AFFTC-PA-11316

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Science and Teacher Researcher (STAR) Program
California Polytechnic State University
San Louis Obispo, CA 93407-4000

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSOR/MONITOR'S REPORT NUMBER(S) N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release A: distribution is unlimited.

13. SUPPLEMENTARY NOTES
CA: Air Force Flight Test Center Edwards AFB CA CC: 012100

14. ABSTRACT
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15. SUBJECT TERMS
Computational Fluid Dynamics, Wind Tunnel, Vortex, Stereoscopic Particle Image Velocimetry (SPIV), Wing, VisIt, Unstructured Grid, Modeling & Simulation, Aerodynamics, Flow Visualization, Numerical Investigation, Aero Suite

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified					412 TENG/EN (Tech Pubs)
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	None	14	661-277-8615

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[a]Science and Teacher Researcher (STAR) Program, Cal Poly San Luis Obispo
[b]Air Force Flight Test Center, Edwards Air Force Base, CA

Wingtip Vortices and the Rationale of This Project

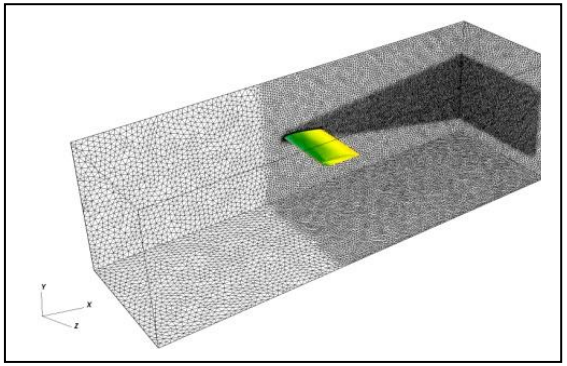
Wingtip vortices are the result of a pressure difference between the top and bottom of an aircraft wing or helicopter rotor moving through air. In military applications, wing tip vortices have adverse effects on towed vehicles and cause additional tail buffeting.[2] In commercial applications, winglets have been installed on passenger aircraft to minimize vortex formation and reduce lift-induced drag.[2]

Visually, wingtip vortices can be thought of as a horizontal tornado (as shown in Figure 1), whose cross-sectional area increases with increasing downstream distance.

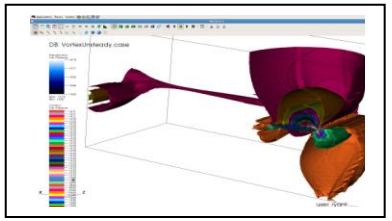
Figure 1 – Visual Representation of Wingtip Vortices

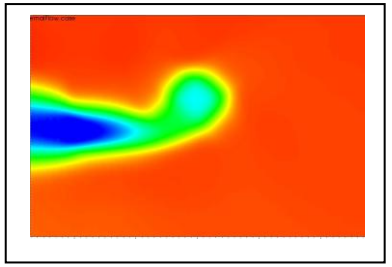
From a computational standpoint, modeling wingtip vortices has been a challenging area of study. It has only been in recent years that computational tools that better resolve and approximate wingtip vortices have been developed. This project sought to expand on gains made by using incrementally more computationally intensive simulations. Determination of the accuracy of the model wingtip vortices was accomplished by comparing simulation results to experimental data.

Methods



Numerical results of simulations sent to visualization program *VisIt*





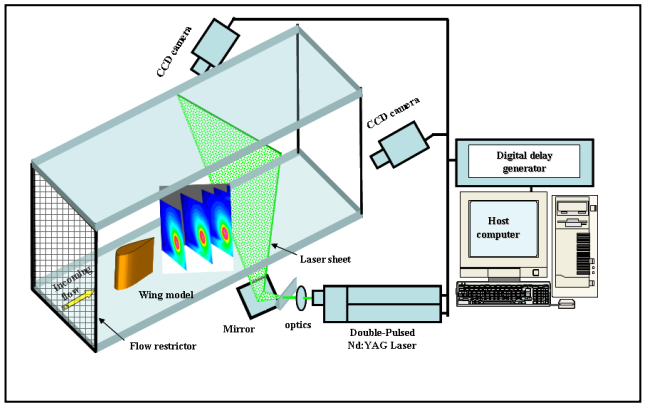
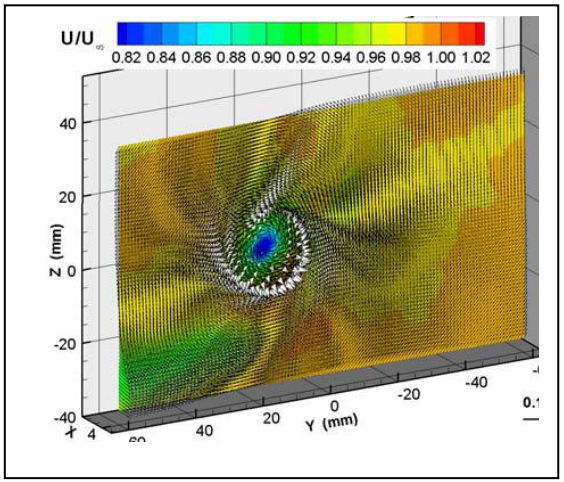
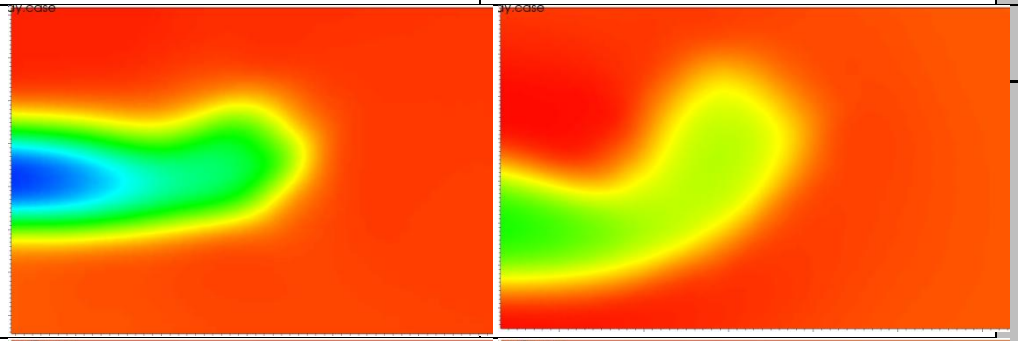
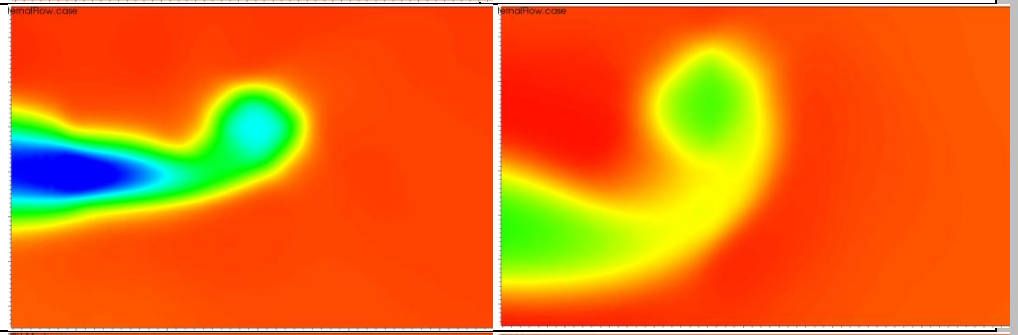
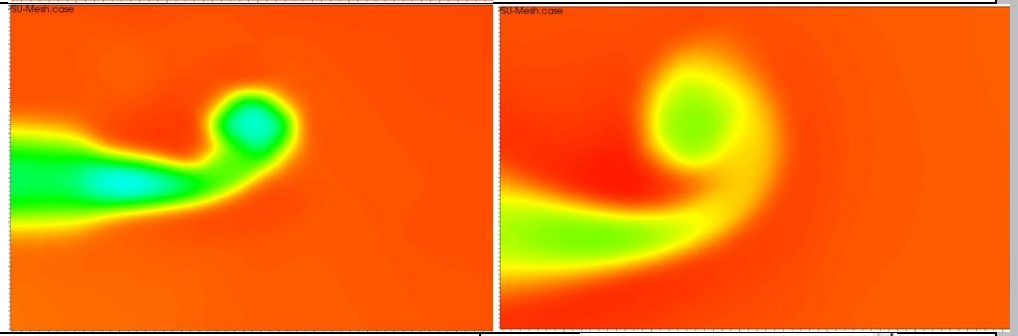
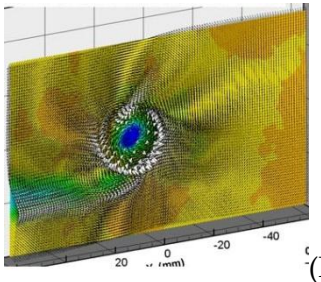
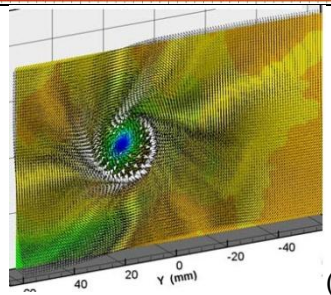


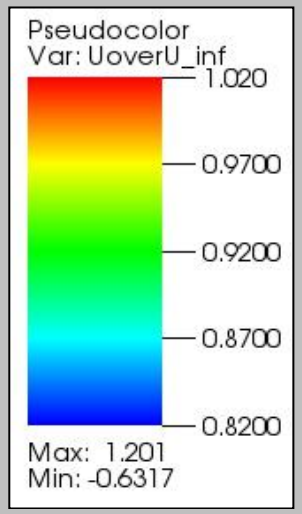
Figure 2 – Experimental Setup using StereoScopic Particle Image Velocimetry (SPIV) (Ref 2)

Data from Iowa State University wind tunnel experiment compared to simulation.



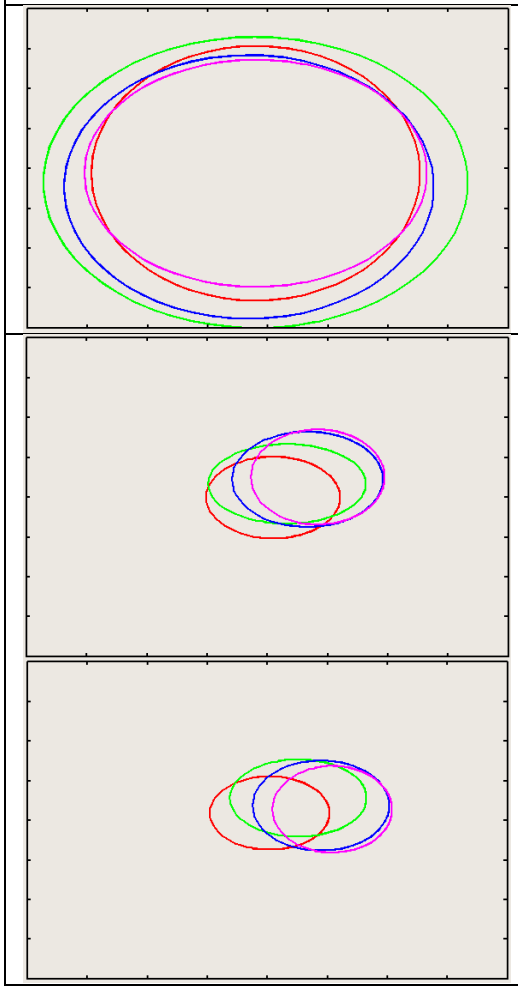
Ref 2

Plots of Instantaneous Velocity over Freestream Velocity and Equivalent SPIV Images			
Simulation	4″ downstream of trailing edge	16″ downstream of trailing edge	**Legends**
Sim0			*Simulation*
Sim3			
Sim7			
SPIV[2]	 (Ref 2)	 (Ref 2)	



Approximate Size and Location of Vortex Cores

From the 2D data collected, the vortex cores were approximated to be ellipses, and size and location were found and plotted for 4″, 8″, 12″, 16″ downstream of TE.



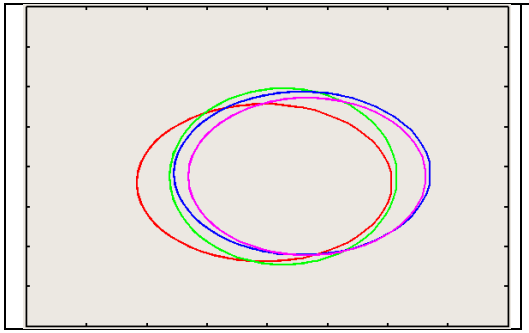
Legend

Purple = 4″ downstream

Blue = 8″ downstream

Green = 12″ downstream

Red = 16″ downstream



Discussion

Instantaneous Velocity over Freestream Velocity with Equivalent SPIV Images

- All three simulations and SPIV show a counterclockwise "curl" forming downstream of the right edge of the wing and from the color scale confirms an expected inverse relationship between vortex velocity and distance from the center (Ref 1).
- The shapes of Sim3 and Sim7 more closely resemble that of SPIV for both downstream locations.
- Sim7 shows more detail than Sim3 and is most like the SPIV plots, as at the 16" mark the plot clearly shows a defined vortex core separated from the horizontal "wash" of the wing.

Vortex Core Size and Location Approximation

As downstream distance from the trailing edge increases:

- Sim0 only shows increase in vortex core area with no core displacement
- Sim3 shows increasing change in area and a core displacement up and to the left.
- Sim7 shows a change in area and a core displacement that approximately follows a concave down parabolic trajectory from right to left which, while exaggerated, resembles what is seen in the SPIV approximation.

Conclusion

- Simulated wingtip vortex development and behavior more closely resembles that of SPIV for finer and denser mesh sizes. The same can be said for vortex core area, and thus the size of the vortices can be approximated by future simulations using a mesh size at least that of Sim7.
- Future work for the simulations need more accurately measured dimensions and coordinates of vortices in the 2D plane, as well as have more exact data from the SPIV experiments. With more accurate measurements there is a need to numerically verify the error of the simulations in comparison to SPIV data to make a better judgment about whether the simulations are reliable to use.
- If the simulations for wingtip vortices are reliable, they can be used to make more efficient use of wind tunnel tests and aid in the design process of aircraft.

Acknowledgements

An additional thank you to the following people: *Russell Billings* at NASA DFRC for his role in my placement at Edwards AFB, and for investing time into our professional development as STAR interns. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013 and Grant No. 0833353. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation.

References

Ref 1: Abbott, I. H., & von Doenoff, A. E. (1959). *Theory of Wing Sections - Including a Summary of Airfoil Data.* Mineola: Dover Publications, Inc.

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Ref 3: Stewart, R. (2002, October 2). *Wake Turbulence Commentary*. Retrieved July 16, 2011, from Robyn's Flying Start: http://www.flyingstart.ca/FlightTraining/PSTAR/7As.htm


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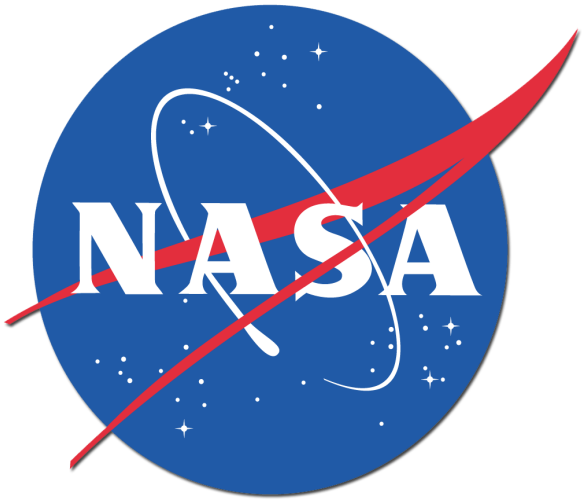

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Figure 1 – Visual Representation of Wingtip Vortices (Ref 3)

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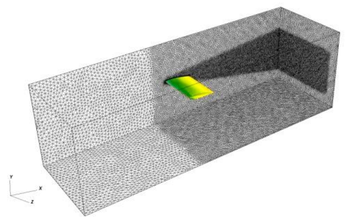

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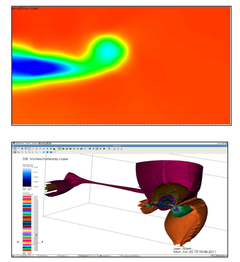

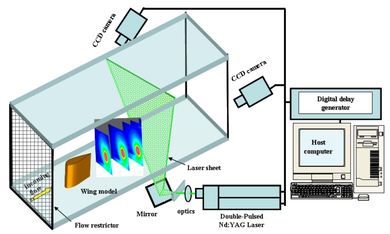

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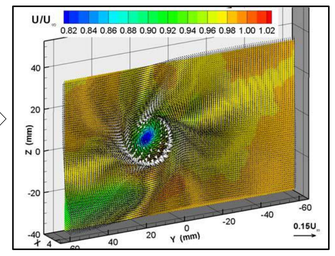
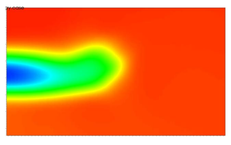
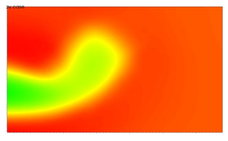
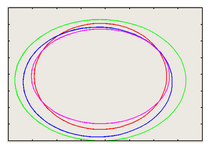
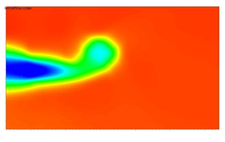
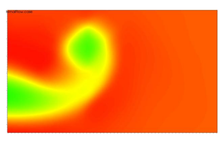
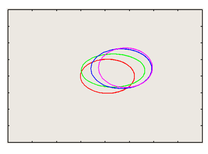
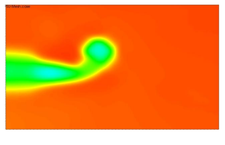
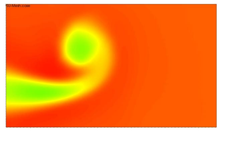
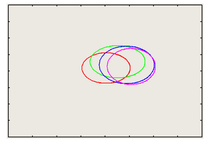
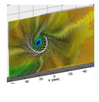
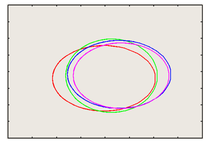


(Ref 2)

Instantaneous Velocity over Freestream Velocity (U/U_∞) and Equivalent SPIV Images

Simulation	4" downstream of trailing edge	16" downstream of trailing edge	Approximate Size and Location of Vortex Cores
Sim0			
Sim3			
Sim7			
SPIV[2]	 (Ref. 2)	 (Ref.2)	

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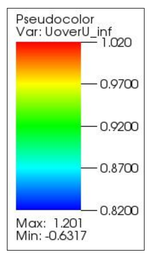
Legends

U/U_∞	Vortex Cores
	Purple = 4" downstream Blue = 8" downstream Green = 12" downstream Red = 16" downstream

Acknowledgements

An additional thank you to *Russell Billings* at NASA DFRC for his role in my placement at Edwards AFB, and for investing time into our professional development as STAR interns. This material is based upon work supported by the S.D. Bechtel, Jr. Foundation and by the National Science Foundation under Grant No. 0952013 and Grant No. 0833353. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the S.D. Bechtel, Jr. Foundation or the National Science Foundation.

References

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